K-Ar ages of Lafayette weathering products: Evidence for near-surface liquid water on Mars in the last few hundred million years

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The question of whether and when liquid water was present at or near the surface of Mars is critical to discussions of the history of Mars. Crucial insight into this question can be gleaned from weathering products in martian meteorites. In particular, the Lafayette meteorite, which has a formation age of about 1300 Ma, contains abundant weathering products (which we will refer to as "iddingsite") that have been suggested to have been formed on Mars [1]. We have studied several hand-picked samples of Lafayette iddingsite, and find apparent K-Ar ages of a few hundred million years. Since iddingsite requires liquid water to form, this sets constraints on the timing of liquid water on Mars.

Background: "Iddingsite" is a complicated mixture of clays, iron oxides, and ferrihydroxides [1]. In Lafayette, it is found in patches and alteration veins, and is abundant enough to make up more than 1% of the meteorite. In our first round of analyses [2], we hand-picked 6 samples of iddingsite and analyzed various noble gases, extracting the gases with a laser. We were partially successful at ^{40}Ar-^{39}Ar analyses, and reported apparent ages of a few hundred Ma.

Samples and procedures: By analyzing the gas in the vials in which the samples were irradiated in the previous experiment, we found that a substantial fraction of the ^{39}Ar created from K in the reactor had recoiled out of the samples, presumably as a result of the fine-grained nature of the samples. However, we found that in samples for which we were confident that we had extracted all the gas, our K abundances agreed reasonably well with INAA-determined abundances. Since keeping the samples in sealed vials compromised the INAA experiment and complicated the noble gas experiment, for the present experiment we have determined classical K-Ar ages, comparing the amount of radiogenic ^{40}Ar with the INAA-determined K abundance.

A total of 19 samples, ranging in mass from 0.5mg to 19.1mg, were separated by hand-picking. The samples were irradiated and counted for INAA at JSC (results have been reported in [3]), and then 13 of them were transferred to Arizona for noble gas analysis (the others have been used for SXRF analysis). Samples were loaded into the extraction line of the mass spectrometer, heated to 150^{o}C to expel adsorbed atmospheric gases, and then each sample was fused with a Lyconix Ar-ion laser. Gas was cleaned up by exposure to hot and cold SAES getters during extraction, and then analyzed in a VG5400 mass spectrometer.

After correction for blanks, approximately half the data still contained a non-zero amount of ^{36}Ar, which could represent terrestrial contamination, martian atmosphere, or cosmogenic Ar. The amount that could be explained by the meteorite's cosmic-ray exposure history (using the production rates of [4]) is small, in all but two cases less than 35% of the uncertainty in the amount of ^{36}Ar. We have assumed that all this ^{36}Ar is terrestrial contamination, and then subtracted an appropriate amount of ^{40}Ar as well. This could be an undercorrection if some of the ^{36}Ar is trapped martian atmosphere, but the amount would be much higher than expected, even if iddingsite does carry some trapped martian atmospheric Kr and Xe [5]. These corrections (blanks plus atmosphere) amounted to nearly half of the ^{40}Ar even in the most favorable cases, but since the isotopic composition of the blanks is well-defined (and atmospheric), the amount of radiogenic ^{40}Ar can be determined to an uncertainty of only about 10% in the most favorable cases.

Results: As can be seen in Table 1, four samples (9B, 9C, 9D and 11C) have amounts of radiogenic ^{40}Ar determined to 25% (1σ) or better. Apparent K-Ar ages for these samples range from 146±35 Ma for 9D to 655±75 Ma for 11C. All the other samples fall within this range (within uncertainty), although most are at the lower end. In fact, no other sample's apparent age overlaps that of 11C. Apparent ages do not correlate strongly with chemistry. Sample 11C, with the old apparent age, is somewhat unusual chemically, as well, with the highest Cr and Zn, and lowest Co and Hg, of the samples analyzed. However, samples with comparable abundances of these elements do not have such extreme ages. Samples 9B and 9C are the two samples in which cosmogenic gas could account for a significant portion of the ^{36}Ar in the sample. If all of the ^{36}Ar were cosmogenic (a possibility for these samples), their ages would be 381 Ma and 416 Ma respectively.

Conclusions:

1) Since many samples have ages far greater than the possible terrestrial age of this meteorite, the iddingsite must be pre-terrestrial (i.e., martian).

2) The samples do not all have the same apparent K-Ar age. This could either reflect multiple episodes of iddingsite formation [1] or differing degrees of partial loss. Such loss could have occurred during the hundreds of millions of years this material was on Mars, during ejection or atmospheric entry, or while on Earth. Sample preparation (in particular, the pre-heating) seems a plausible explanation. However, in the previous experiment, in which a slightly lower pre-heating temperature would have made such loss less likely and sealed vials would have made it easier to detect, we obtained similar ages (roughly 200-350 Ma), and saw no evidence of loss during pre-heating. It may be worth noting that that sample 11C came from an interior sample of the meteorite, while samples 9A through 9K came from a fusion-crusted chip of the meteorite. However, all samples were more than 1 mm from the fusion crust, beyond the range where thermal effects were detectable either microscopically or with an electron microprobe. Also, sample 11A was from the sample chip as 11C, yet it gave an age several sigma lower than that of 11C.

3) The most likely time for this rock to have been exposed to liquid water might have been at, or shortly after, its formation 1300 Ma ago, since an igneous event capable of generating such a rock would also be capable of melting subsurface water in the vicinity. However, the oldest apparent age is still only about half the formation age. The same caveats about the possibility of gas loss apply.

4) Two lines of evidence reported previously suggest that the water responsible for the formation of the iddingsite was near-surface, rather than magmatic, water. First, the weathering products formed at low temperatures [1]. Second, the iddingsite seems to contain a substantial amount of Kr and Xe [2], which may have been acquired from water in contact with the martian atmosphere [5].

Although there are some caveats, we believe the most likely explanation of all our data is that the weathering products in the Lafayette meteorite formed as a result of the action of near-surface liquid water on Mars in one or more events no more than 700 Ma ago.

References: [1] A. H. Treiman et al. (1993) *Meteoritics* **28**, 86-97; [2] T. D. Swindle et al. (1995) *Lunar Planet. Sci XXVI*, 1385-1386; [3] A. H. Treiman et al. (1997) *J. Geophys. Res.-Planets*, in press; [4] M. Freundel et al. (1986) *Geochim. Cosmochim. Acta* **50**, 2663-2675; [5] M. J. Drake et al. (1994) *Meteoritics* **29**, 854-859.

Table 1: K and radiogenic ^{40}Ar in Lafayette weathering products

Sample	Mass	K_2O	^{40}Ar	Age
9B	19.06	0.366(7)	3.49(29)	274(22)
9C	10.57	0.432(17)	6.08(70)	392(44)
9D	4.38	0.833(30)	4.1(1.0)	146(35)
9E	2.66	0.940(34)	6.3(2.0)	195(60)
9F	2.09	0.721925)	0.2(7.6)	10(300)
9G	1.32	0.562(26)	5.8(5.2)	290(250)
9I	2.17	0.670(26)	9.2(3.4)	380(130)
9K	1.34	0.760(30)	9.1(3.4)	340(110)
11A	7.54	0.583(22)	1.58(89)	83(45)
11C	6.35	0.377(13)	9.6(1.3)	655(75)

Mass in μg, K_2O in wt.%, ^{40}Ar in 10^{-6}cm^{3}STP/gm, age in Ma. Numbers in parentheses are 1σ uncertainties.